Measurement of Junction Temperature in AlGaN/GaN HEMTs

GAO Li 1*, GUO ChunSheng 2, LI ShiWei 2
[1] China Electronics Standardization Institute, AnDingMen East Street No.1, Beijing, 100176, China.
[2] Beijing University of Technology, No.100 Pingleyuan, Beijing, 100124, China.
*Phone: +8610-64102160 Fax: +8610-64102159 Email: gaoli@cesi.cn

***Abstract*- In this study, the maximum spatial resolution of infrared thermal imager is 3 µm, and the gate length of AlGaN/GaN HEMTs is between 0.2 µm and 1 µm. Therefore, the infrared thermal imaging instrument measurement results are only an average temperature that is lower than the actual temperature. By combining infrared thermal imaging with Sentaurus TCAD simulation, the junction temperature of AlGaN/GaN HEMTs can be accurately measured. First, with the infrared thermal imager under different loading power settings and the shell temperature of the AlGaN/GaN HEMT junction temperature increase, the Sentaurus TCAD of AlGaN/GaN HEMTs for steady-state and transient simulations is measured. Then, the use of the infrared thermal imager is measured under different power settings of AlGaN/GaN HEMTs active region temperature as the boundary condition to optimize parameter model. Then, the junction temperature of the AlGaN/GaN HEMTs is extracted from the model, which has a resolution of 0.05 µm -2 µm**.

***Keywords:* AlGaN/GaN HEMTs; Junction Temperature; Infrared Image Method; Sentaurus TCAD Simulation Method;**

I. INTRODUCTION

Gallium nitride high-electron-mobility transistors (HEMTs) offer a viable solution to the need for efficient solid-state operation at RF frequencies [1], [2]. Due to its wide band gap, high breakdown field, current density, and saturated velocity, this material system is well suited for high temperature and high power applications from microwave to millimeter-wave frequencies [3]. However, the channel temperature of the device would substantially increase to a hundred degrees above the ambient base temperature when operating in a high power dissipation condition. Commonly known as the self-heating effect, this causes a reduction in device performance and decrease in the Mean Time to Failure (MTTF) [5]. Therefore, the accurate measurement of channel temperature is required to three-temperatures DC or RF life tests.

Several experimental techniques such as infrared thermal imaging and Raman spectroscopy are often used, but they have several limitations [6]. First, they usually impose special requirements on device geometry, such as large gate-to-drain gap and limited field plate and air bridge configuration for direct access to the device from the top, and it is difficult to measure a fully packaged device [7]. In addition, optical techniques measure vertically averaged temperature of the GaN layer [8]. In recent years, Raman spectroscopy was successfully employed to measure the temperatures of AlGaN/GaN HEMTs. Raman measurements allow for the accurate measurement of the GaN device channel temperature with a high spatial resolution [9, 10, 11]. However, Raman spectroscopy is slow, and it requires a large integration time to achieve the best resolution.

In this paper, we use the Sentaurus TCAD to build a model of AlGaN/GaN HEMTs. The infrared imaging of the active region temperature distribution of the AlGaN/GaN HEMTs serves as a boundary condition to determine the model parameters. Then, the surface temperature distribution of the AlGaN/GaN HEMTs under different power settings and different resolutions are measured using infrared thermography to optimize Sentaurus TCAD parameters. Finally, the junction temperature of HEMTs with a gate size near 0.05 µm-2 µm is extracted from the model. The entire testing process is shown in Figure 1.

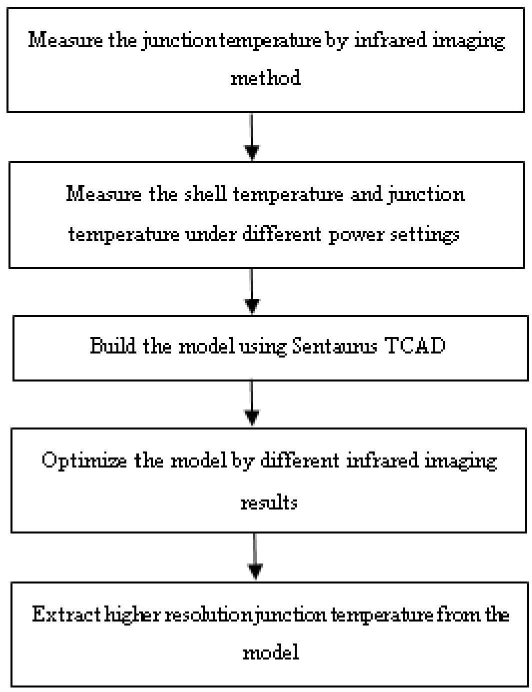

Fig. 3 The entire testing process .

II. EXPERIMENTS

2.1 Device fabrication

The devices used in this paper are the 0.5-µm GaN HEMTs with a field plate. The AlGaN/GaN heterostructure was grown using metal organic chemical vapor deposition (MOCVD) on a SiC substrate. The gate length, gate width, gate-source spacing, and gate-drain spacing were 0.5, 350, 2, and 4 µm, respectively.

The SiC, GaN, AlGaN widths were 100 μm, 2 μm and 25 μm, respectively. The cross-section is shown in Figure 2. Cross sectional transmission electron microscope (TEM) samples were prepared via the lift-out technique using a focused ion beam. The shapes of the gate and field plate are clearly displayed, as shown in Figure 3.

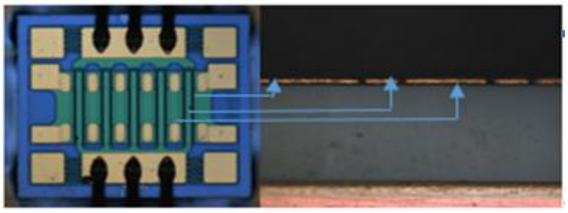

Fig. 2 AlGaN/GaN HEMTs construction.

(a) (b)

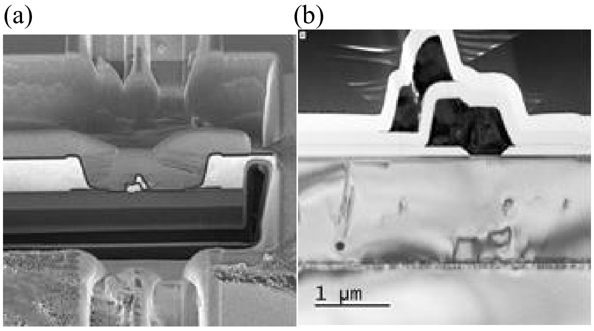

Fig. 3 (a) Cross-sectional view and (b)the shape of the gate and field plate

To obtain the characteristics of the device, the parameters of the material should be set up during the modeling process. The material parameters are shown in Table I.

Table I The material parameters

Material parameters	Unit	GaN	AlN	SiC
Electron mobility	$cm^2/(V\cdot s)$	1000	300	1140
S-R-H life	Ns	1	1	1
Band gap width	eV	3.47	6.2	3.26
Relative dielectric constant	L	9.5	8.5	9.7
Electron saturation rate	cm/s	1.5×10^7	1.5×10^7	2×10^7
Thermal conductivity	W/(K • cm)	2	2.85	3.7
Lattice hot melt	$J/(K\cdot cm^3)$	3.0	1.94	2.2
Thermal diffusion factor	cm^2/s	0.43	1.47	1.67

2.2 Infrared imaging measurement

The measurement system includes power supplies, a device clamp, an anti-self-excited circuit, a thermal infrared imager, a temperature gauge, and a heated platform. The measurement process is as follows: first, the HEMT device undergoes testing through device clamp fixed on the anti-self-excited circuit, and measured by the thermal infrared imager with a power applied drain-source voltage V_{ds} and gate-source voltage V_{gs}. By adjusting the drain-source voltage V_{ds}, gate-source voltage V_{gs}, drain-source current I_{ds}, the device case temperature and the junction temperature were measured at different power settings: 1.4 W, 2.8 W, 5.6 W, 8.4 W, 11.2 W, 14 W.

Experiments are a constant drain-source voltage V_{ds} 28 V, by changing the gate voltage V_{gs} to change the drain-source current I_{ds}. The IR test results under different values of power are shown in Table II. The thermal infrared imager measured spatial resolution is 7 μm.

Table II The IR test results under different power settings

(platform temperature 70℃)

I_{ds}/mA	V_{ds}/V	P/W	T_j/℃
100	28	2.8	92.6
200	28	5.6	116.6
300	28	8.4	143.3
400	28	11.2	171.8
500	28	14.0	197.6

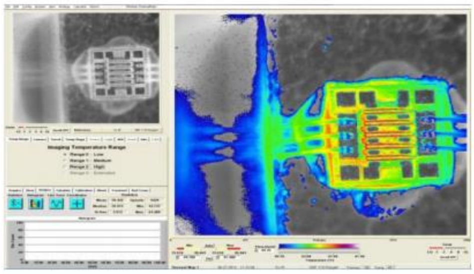

Fig. 4 Chip temperature distribution under power

2.3 Raman spectroscopy measurement

After measuring the HEMT devices, Raman spectroscopy was used to determine the temperature rise of the device, and we compared these results with the results measured using the infrared thermal method.

The test conditions and the infrared thermal method were the same, that is, the drain-source voltage V_{ds} of 28 V was achieved by changing the gate voltage V_{gs} to change the drain-source current I_{ds}. The relationship between phonon frequency and temperature were measured before power loading. After recovery to room temperature and a period of stability, then the device power was loaded and measured using Raman spectroscopy. By adjusting the gate voltage, Raman spectroscopy was used under different conditions in which I_{ds} was 100 mA, 200 mA, 300 mA, 400 mA and 500 mA. Thermal resistance was calculated according to the temperature coefficient and Raman spectra.

The thermal resistances acquired by the infrared imaging method and Raman spectroscopy are compared. With the Raman method, which has a high spatial resolution of up to 1 μm, but a lower temperature resolution, it is not possible to accurately measure the temperature of the highest point of the chip. It can be seen from Table III that the thermal resistances change trend is consistent between the infrared imaging method and Raman spectroscopy, although the values of thermal resistances are not equal.

Table III The result of the Raman test under different power settings

Power/W	Raman（R_{th}℃/W）	IR（R_{th}℃/W）
2.8	4.9	5.3
5.6	5.4	5.6
8.4	5.8	5.9
11.2	6.1	6.3